Apical Root Resorption Under Orthodontic Therapy*

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INTRODUCTION AND HISTORY

A study of apical root loss concerned primarily with orthodontic procedures was reported first in the literature by Ottolengui[1] in 1914. However, root resorption had been acknowledged as a problem of consequence by the dental profession for over half a century. According to a recent extensive survey of the literature by Henry and Weinman,[2] the first recorded reference is attributed to Bates[3] in 1856. That it remains a matter of general concern is evidenced by today's standard texts on dental pathology which without exception are replete with descriptions, pictures, and classifications of various types of root resorption: exfoliation of the deciduous dentition, traumatic or pressure resorption, inflammatory resorption, and resorption due to idiopathic causes. Presently, however, the problem of root loss has receded from the first line of investigational interest. During the period from 1926 through the early 1940's it was a matter of primary contention and only through a review of the writings of the men concerned can one gain an insight into the controversies that flourished both here and abroad.

Ottolengui's report on 1914 was received with little trepidation by orthodontists. On the other hand, just twelve years later, the profession reacted with great concern to a report on apical root loss presented by Ketcham[4] in 1926 and followed by a subsequent report in 1929.[5] Ketcham's study consisted of a radiographic survey of 385 treated cases from his orthodontic practice, and according to his own evaluation the conditions of apical root loss were "so startling, so potent in danger to the orthodontic patient, so prolific of recrimination to the orthodontist himself" that he "made bold" to present his findings to the orthodontic world. Reading these somewhat dramatic statements in retrospect, it would seem that Ketcham had anticipated a greater than ordinary reaction, and rightly so. In all probability this impact was due greatly to the fact that in the twelve years intervening the reports of Ottolengui and Ketcham, dental radiography had become widely used as a diagnostic adjunct by the dental profession and many men were therefore able to make an individual evaluation of the problem at hand. Nevertheless, Ketcham's dramatic evaluations were in themselves a catalyst, challenging every orthodontist to review his own experiences. There resulted numerous investigations involving not only the question of apical root loss but the whole histologic process of tooth movement during orthodontic intervention, both on experimental animal material and human patients. Schwarz, Herzberg, Marshall, Oppenheim, Gottlieb, Orban, Stuteville, Kronfeld, Becks, and others contributed continuously during the period from 1929 to 1942.

Marshall, [6 7 8 9] as a result of his

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work with monkeys, believed apical root loss to be due to dietary factors. Becks,[10 11 12] in a voluminous study on human material noted a coexistence of root structures and endocrine imbalances. Schwarz[13], Orban[14], Oppenheim[15 16 17], and Stuteville[18 19] all endorsed the theory that root loss was caused by the excessive forces engendered by the orthodontist's manipulation of appliances to move teeth to desired positions. Hemley[20] alleged that horizontal movements of teeth through bone had a tendency to cause apical root resorption. Oppenheim[15] also postulated that the shape of the roots of the anterior teeth (maxillary in paricular) predisposed them to apical root loss. Another conviction was that resilient or non-stable appliances caused apical root resorption.

Reporting his investigation in 1941, Hemley[20] concluded that the incidence of root resorption can be reduced to the extent that it need not be regarded as hazardous to orthodontic treatment; and judging from a survey of the more recent publications this would see to be the view of orthodontists generally today since most are convinced that with proper handling of appliances and control of forces engendered therein, the amount of root loss during treatment in a majority of cases can be considered as not detrimental to the life span or function of the dental units. Further impression is gained from the literature that the histologic process of tooth movement caused by orthodontic intervention and the effects and results are well documented and understood.

This study presents additional aspects of the problem of apical root resorption and an attempt has been made to evaluate and discuss this material in the light of the findings of previous investigations.

The study at hand is concerned with the phenomenon, "apical root loss or resorption". Since the literature is sometimes confusing in reference to the effects of root resorption on the root surface of the tooth, a definite distinction of terms is made. In effect, "apical root loss or resorption", causes a definite shortening of the root length of the teeth. The effect is permanent and irreparable, and understandably causes great concern to the orthodontist.

A second factor not involved here is "cementum resorption", the subject of an excellent study by Henry and Weinmann.[2] By way of distinction, "cementum resorption" occurs on all sides of the tooth root. It is thought that trauma to the individual tooth causes this effect and that eighty-five per cent of these areas show some repair with secondary cementum and that most of these repairs become anatomically complete.[2]

Methods and Materials

Various methods of study were outlined and followed. Before and after treatment intra-oral x-rays were obtained and examined in a manner somewhat similar to the methods of Hemley,[20] Becks and Cowden.[12] Lateral cephalometric head films were used to compile pertinent measurements for statistical comparisons of findings to determine possible correlations of apical root resorption with reference to sex, age of the patient, and length of treatment. These films were used to evaluate also the effect of apical root loss of the different types of tooth movement found to occur in the maxillary central incisors. The last approach was a purely experimental supplement of root surface area studies, which attempted mechanical simulation of root resorption. Each of these methods of study is presented separately in detail.

I. *Before and after treatment intra-oral x-rays of orthodontic cases.* Sixty-

nine sets of intra-oral x-rays were used; fifty-four sets selected from records of the orthodontic clinic at the University of Washington, and fifteen sets obtained from the private practice of a member of the faculty of the department of orthodontics.

All cases in this study were full treatment cases using the edgewise appliance with a continuous arch technique. The total number of teeth counted was 1745. Third molars were not included in the total number of teeth counted. All teeth were banded and subjected to orthodontic appliances with the possible exception of the maxillary and mandibular second molars which may or may not have erupted at the inception of treatment.

Of the sixty-nine cases, forty-three were four bicuspid extraction cases of various combinations, two were upper first bicuspid extraction cases, and three were extraction cases involving teeth other than bicuspids. Twenty-one were non-extraction cases. No mixed dentition cases were included.

A data chart was set up providing a square for recording the evaluation of each tooth after inspection, using the following criteria for estimating the amount of apical root loss:

Slight: minimal blunting of the root apices. (Figure 1.)

Moderate: up to approximately one-fourth root length loss. (Figure 2.)

Excessive: over one-fourth root length loss. (Figure 3.)

Questionable: possible traces of resorption not positively identifiable because of distortions due to film placement or differences in x-ray cone angulation.

The dividing line between the categories of root loss was difficult in some cases, particularly between the categories "slight" and "moderate", since a great divergence of root lengths appeared on the films because of elongation or foreshortening of root lengths due to different radiographic techniques of film placement and a variance in angulation of x-ray cones by different operators taking the films. As a result, the films were inspected separately by three individuals and compared only after all opinions had been tabulated. Inspection was done by two members of the orthodontic staff and the author. In the event that differences in evaluation of the amount of root loss occurred, the assessment of that tooth was placed in the category of majority opinion. If, as sometimes occurred, three different evaluations of root loss were recorded (such as "no resorption", "questionable", or "slight") the average of the three evaluations was tabulated.

II. *Linear measurement of apical root loss from before and after treatment lateral cephalometric head films.* Sixty-two lateral head films were available for study; forty-six from the files of the University of Washington Department of Orthodontics, and sixteen sets from the private practice of a member of the staff of the department. All films had been taken with the Broadbent-Bolton cephalometer in the Department of Orthodontics. Treatment of cases from the department had been done by graduate students under the direction of staff members. All were full treatment cases using the edgewise appliance with a continuous arch technique.

Of sixty-two cases, forty-two were four bicuspid combination extraction cases; two were upper first bicuspid extraction cases, and eighteen were non-extraction cases. Sixty of the sixty-two cases were used in the intra-oral portion of this study. No mixed dentition cases were included.

Of the sixty-two cases, thirty-nine were female and twenty-three male, with an age range at the beginning of

Fig. 1. Above, maxillary pre and post treatment, slight loss. Below, mandibular pre and post treatment, slight loss.

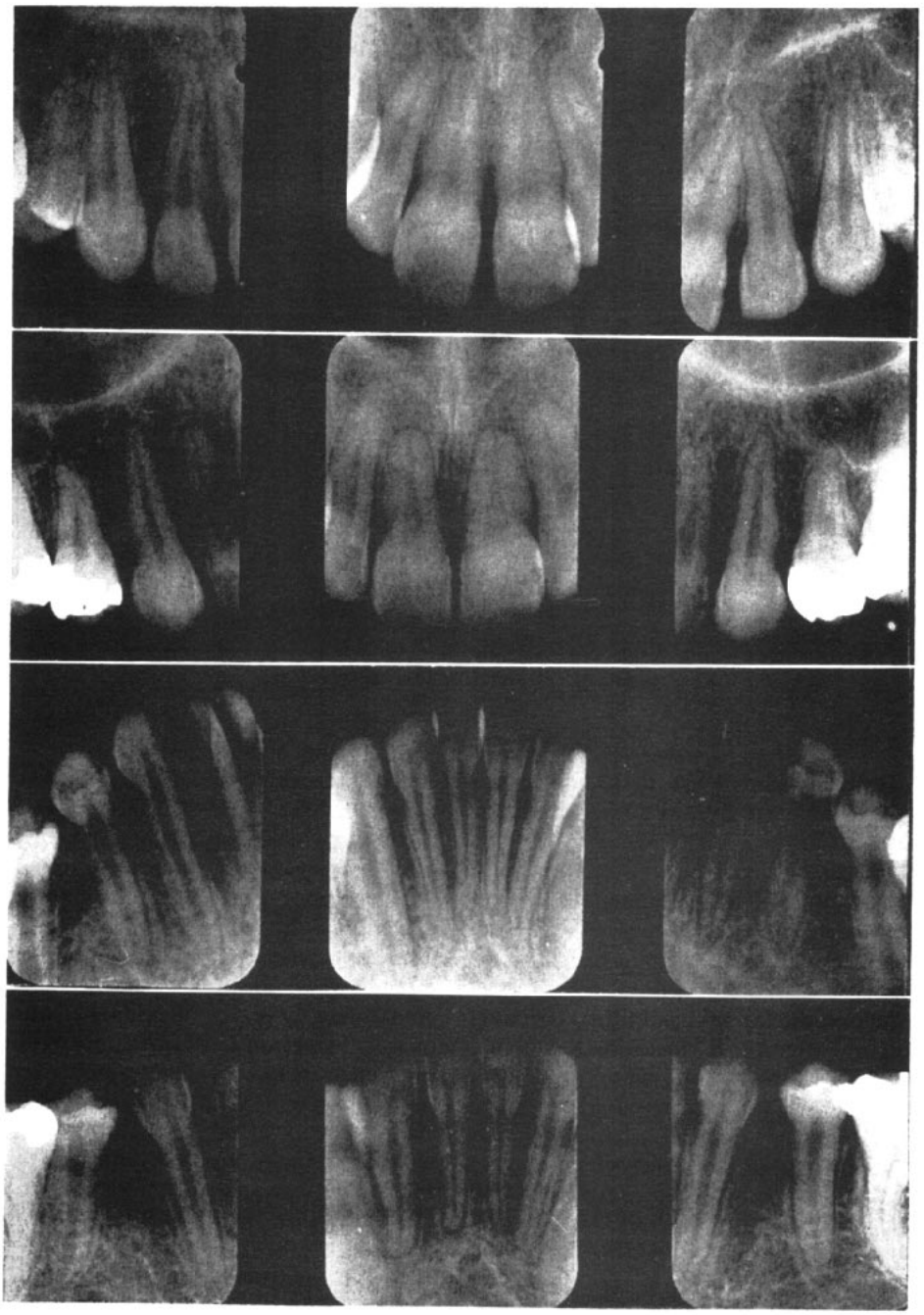

Fig. 2. Above, maxillary pre and post treatment, moderate loss. Below, mandibular pre and post treatment, moderate loss.

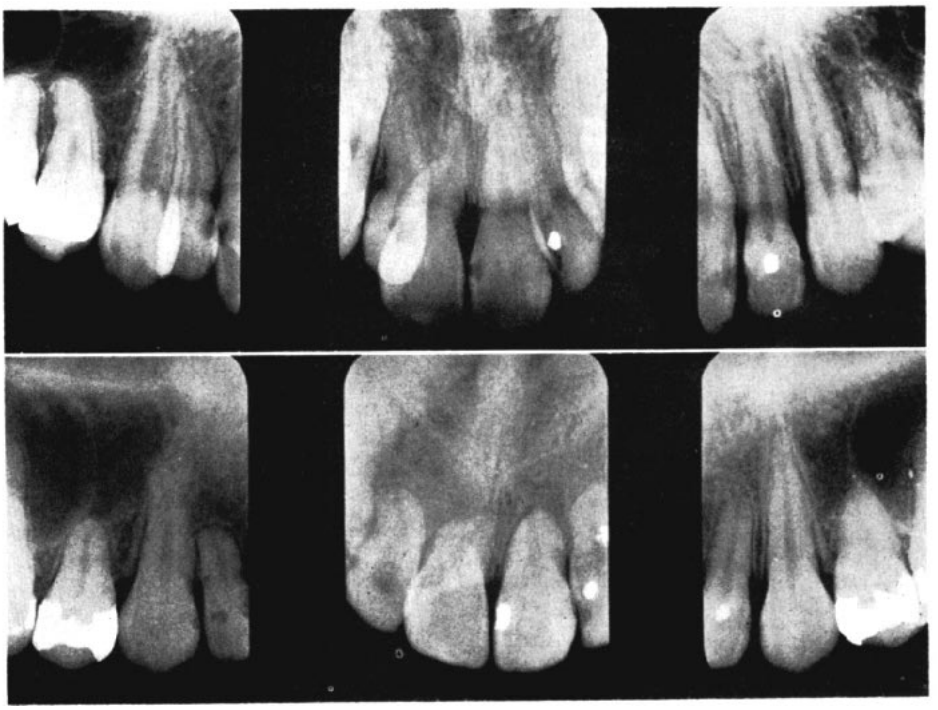

Fig. 3. Excessive loss, maxillary pre and post treatment.

treatment from 10.75 to 18.5 years for the female group and 11.5 to 16.5 for the male.

It had been noted on intra-oral radiographs that maxillary and mandibular central and lateral incisors were the teeth affected to the greatest degree by apical root resorptions. As a consequence, the lateral head films were used in an attempt to measure the actual length of these teeth before and after treatment for further study.

At an early point, it became apparent that this particular part of the survey would be successful only inasmuch as the tooth length of the maxillary central incisor could be measured with accuracy. The apices of the maxillary lateral incisors and those of the mandibular lateral and central incisors were obscured beyond evaluation by other structures or by the density of the bone surrounding them.

It was felt, however, that results of tooth movements of the upper central incisors would be applicable to the other anterior teeth since they moved orthodontically in a similar manner. Therefore, measurements were taken, directly from the head films, of the actual length of the maxillary central incisors before and after treatment. The difference between these two lengths was considered to be the amount of apical root loss. Correctional millimeter scales were used to take into account the magnification of root lengths caused by film target distances and the distance of the film cassette from the patient's head. Measurements were recorded to the nearest half millimeter.

In the main, the apices of both upper central incisors resorbed to the same degree, but in occasional instances re-

sorption of one varied in extent with that of its mate. When this occurred, the length of the shorter of the two roots was used, thus assessing the amount of apical root loss at its maximum throughout the study.

Measurements of apical root loss were compared statistically to determine possible correlations in three separate categories.

Sex differences. Experimental findings were treated statistically to determine any possible sex difference in the amount of apical root loss.

Influence of age of the patient at the inception of treatment upon loss of tooth structure. The "age at inception of treatment" is the date of cementation of the orthodontic bands onto the maxillary incisors, although other segments of the arch may have been under treatment for some months.

Influence of length of treatment on the amount of root loss. The "length of treatment" is defined as the length of time between the date the bands were actually cemented onto the maxillary centrals and the date of removal of bands from these teeth.

The above delineations are specifically drawn in view of the fact that many orthodontists are of the opinion that the greater length of time the forces engendered by treatment are active, the greater the degree of root resorption; and that the younger the patient at inception of treatment, the incidence of apical root loss is lessened. It was necessary also to pinpoint the length of time that maxillary incisors were under treatment, for although other segments of the dental arches were treated for longer periods of time than were the anterior segments, active loss of apical root structures was not considered to start until forces were actually applied to these teeth; i.e., forces which commenced with the cementation of the bands and the utilization of arch wires to direct the movement of the maxillary incisors. Furthermore, it was felt that root resorption had stopped with removal of the bands from the maxillary incisors since the incisors had been in the desired position for some weeks prior to removal of the bands, and since movement of the teeth would be negligible under the influence of retaining devices little additional root loss would occur.

III. *Measurement of angular change from before and after treatment lateral cephalometric head films.* The lateral cephalometric head films were used in a second survey for the purpose of relating the amount of root resorption to the amount of angular change in the axial inclination of the maxillary central incisors. Sixty-one sets of before and after treatment head films were used.

Cephalometric tracings were made in each case before and after treatment, of the maxillary central showing the greatest amount of apical root loss and the associated bony structures including outlines of the hard palate, floor of the nose and anterior nasal spine. The tracings then were superimposed according to accepted methods,[21] to show the amount and direction of movement of the traced maxillary central. To determine the amount of angular change or amount of tooth movement, a base line was drawn from anterior nasal spine to posterior nasal spine, and a line through the long axis of the central incisor. The angles made by intersection of these lines were measured by protractor and the differences recorded as indications of the angular change of axial inclination or the amount of movement of the tooth during orthodontic treatment. Three distinct types of tooth movements were found to occur to the maxillary central incisors.

The angular change of the teeth in each type of movement was recorded.

1. *Apical tipping.* The apex stayed in its original position or was extruded slightly during treatment but remained in the same perpendicular plane. (Figure 4.)

2. *Anterior or posterior apical displacement.* The apex moved in a horizontal direction, anteriorly or posteriorly. (Figure 5.)

3. *Lingual bodily movement.* Bodily movement of teeth lingually from their original position. (Figure 6.)

IV. *Linear measurement of the movement of apices of the teeth typed "lingual bodily movement" from before and after treatment lateral cephalometric head films.* The apices of the teeth moved lingually. Movement was measured with correctional millimeter scales to allow for magnification of film object.

The statistical tests used to test and evaluate data in Parts II., III., and IV. were the tests of coefficient of correlation and the Student "t" test.

V. *Surface Area Studies.* It was sought to test experimentally the amount of retentive surface area of a tooth root lost by the periodontal membrane as a result of apical root resorption under treatment. The teeth selected for study were extracted maxillary and mandibular centrals and laterals.

Root resorption was mechanically simulated by reducing the root length by grinding in 2 mm. levels and determining the retentive area lost to the periodontal membrane. Grinding was done by means of an abrasive disc. After each 2 mm. decrease, a piece of 0.0005 inch tin foil was adapted to the root. Care was taken not to burnish areas that could not be flattened out easily. The tin foil, in each case, was extended to a definite base line around the neck of the tooth; namely, the line joining the highest point of cemento-enamel junction of the labial and lingual surfaces. The tin foil was removed and laid flat. The root area then was determined by means of a compensating polar planimeter, an instrument which measures the area of an irregu-

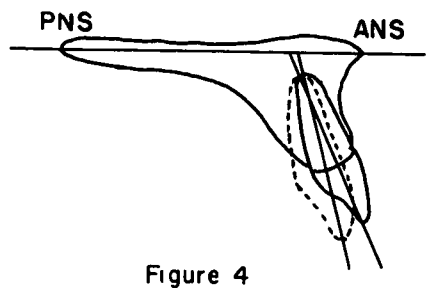

Figure 4

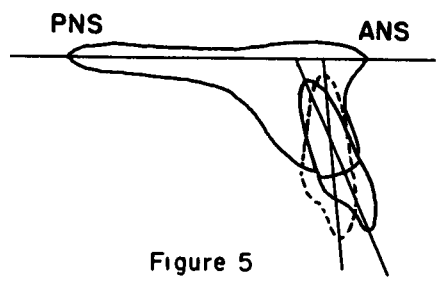

Figure 5

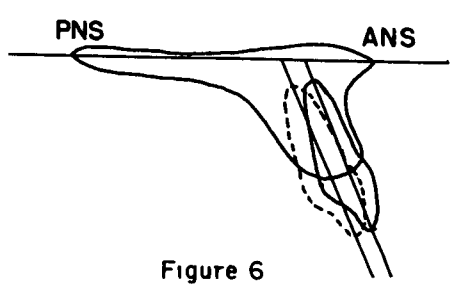

Figure 6

Fig. 4. Apical tipping.

Fig. 5. Anterior or posterior apical displacement. Posterior tipping moves the apex lingually and the crown anteriorly.

Fig. 6. Bodily movement, lingually.

Tooth	No. Studied	Degree of Resorption: None No.	None % total	Questionable No.	Questionable % total	Slight No.	Slight % total	Moderate No.	Moderate % total	Excessive No.	Excessive % total
1|1	138	4	2.9	18	13.0	86	62.3	28	20.3	2	1.5
$\overline{1\|1}$	138	24	17.4	15	10.8	96	69.5	3	2.2	0	0.0
2|2	135	11	8.2	11	8.2	78	57.7	32	23.7	3	2.2
$\overline{2\|2}$	138	29	21.0	18	13.0	88	63.7	3	2.2	0	0.0
3|3	137	71	51.8	28	20.4	33	24.0	5	3.6	0	0.0
$\overline{3\|3}$	138	93	67.4	20	14.5	23	16.6	2	1.4	0	0.0
4|4	58	54	93.1	0	0.0	3	5.1	1	1.7	0	0.0
$\overline{4\|4}$	73	65	89.0	2	2.7	6	8.2	0	0.0	0	0.0
5|5	124	104	83.8	6	4.8	14	11.2	0	0.0	0	0.0
$\overline{5\|5}$	117	103	88.0	2	1.7	10	8.5	2	1.7	0	0.0
6|6	138	130	94.2	3	2.2	4	2.9	1	0.7	0	0.0
$\overline{6\|6}$	135	110	81.5	6	4.4	19	14.1	0	0.0	0	0.0
7|7	138	137	99.3	1	0.7	0	0.0	0	0.0	0	0.0
$\overline{7\|7}$	138	132	95.7	0	0.0	6	4.3	0	0.0	0	0.0
Total Max	868	511	58.8	67	7.7	208	25.1	67	7.7	5	0.6
Total Mand.	877	556	63.4	63	7.2	248	28.3	10	1.1	0	0.0
Grand Total	1745	1067	61.1	130	7.3	466	26.7	77	4.3	5	0.3

Table. I. Tabulation of teeth: incidence and degree of apical root loss.

lar figure.[22] The area of the original root length had been determined previously in the same manner. Each successive area loss could be determined and a percentage of area loss for each level of root length obtained.

Findings

All materials, data, and statistical calculations for this study are on file at the University of Washington, Department of Orthodontics.

The results from inspection in intraoral x-rays are shown in Table I. Gross inspection of tabulated results of tooth susceptibility between right and left sides of the dental arches proved symmetrical, therefore results were not separated into these categories.

A total of 1745 teeth, 868 in the maxilla and 877 in the mandible, was tabulated. In all cases the numbers of teeth studied in each group are nearly equal with the exception of the maxillary and mandibular bicuspids. The smaller numbers here represent teeth eliminated through an extraction procedure for orthodontic therapy.

Of the total 1745, 1067 (61.1 per cent) showed no apical root loss, 130 teeth (7.4 per cent) fell into the class "questionable", 466 teeth (26.8 per cent) fell into the class "moderate" Only 5 teeth (0.3 per cent were classified as "excessive".

The degree of root resorption "questionable" is excluded from the discussion as a clinically insignificant amount.

Of 548 teeth classed as "slight",

"moderate" and "excessive" in degree of apical root loss, 419 (76.4 per cent) were maxillary and mandibular centrals and laterals. Three hundred forty-six (82.6 per cent of those were tabulated "slight", 66 (15.6 per cent) "moderate", and 5 (1.2 per cent) "excessive". By comparing the numbers and percentages of the maxillary and mandibular centrals and laterals in each degree of resorption, the following information was gained. The number of mandibular centrals (96) and laterals (88) classed as "slight" was greater by a small margin than their maxillary opposites (86 and 78 teeth respectively). The number of mandibular centrals (3) and laterals (3) classed as "moderate" dropped considerably under the number shown by the maxillary centrals (28) and laterals (32). No mandibular centrals or mandibular laterals received a rating of "excessive", while five maxillary centrals and laterals received that distinction. The foregoing statements show that a greater number of maxillary centrals and laterals were involved with some degree of root resorption than were their mandibular opposites.

The incidence of root loss drops sharply from the levels shown in the anterior region when the cuspids are reached. Approximately 20 per cent of the cuspids received the degree of "slight" root resorption, while only 2.5 per cent fell into a "moderate" classification. No cuspids were classed in the "excessive" category. The teeth beyond the cuspids in the dental arches show even less incidence to the various designations of resorption. Small percentages of the teeth fell into the category "slight", only an occasional tooth into "moderate". No teeth fell into the degree "excessive". The differences in the numbers of bicuspids and molars in both arches involved with some degree of root loss can be explained on the basis of space closure due to extraction therapy.

Totalling the percentages of the teeth in each class of resorption shows a gross estimate of the susceptibility of each tooth. Maxillary centrals (84.1 per cent) and laterals (83.2 per cent) have near equal susceptibility, followed in incidence by the mandibular centrals (71.7 per cent) and laterals (65.9 per cent). Maxillary cuspids (27.6 per cent) are more susceptible than are their mandibular opposites (18 per cent). This is followed by the mandibular first molars (14 per cent). Maxillary second bicuspids (11.2 per cent) and mandibular second bicuspids (10.2 per cent) show a close equality and were slightly higher in susceptibility than the mandibular first bicuspids (8.2 per cent) and maxillary first bicuspids (6.8 per cent). Following in order were mandibular second molars (4.3 per cent), maxillary first molars (3.6 per cent), and maxillary second molars (0.0 per cent).

The test, coefficient of correlation ("r") was used to test correlation of the amount of apical root loss with the following items:

1. Age of the patient at inception of treatment.
2. Length of treatment.
3. Amount of tooth movement as represented by change in three different types of movement demonstrated; namely, "apical tipping", "anterior and posterior apical tipping" and "lingual bodily movement".
4. Movement of the apices lingually as measured in millimeters in the type of movement designated "lingual bodily movement".

The Student "t" test ("t") was used to test the significance of the values for "r" and to test for significant differences in the amount of root resorption occurring under the three different types of tooth movement. A "t" value

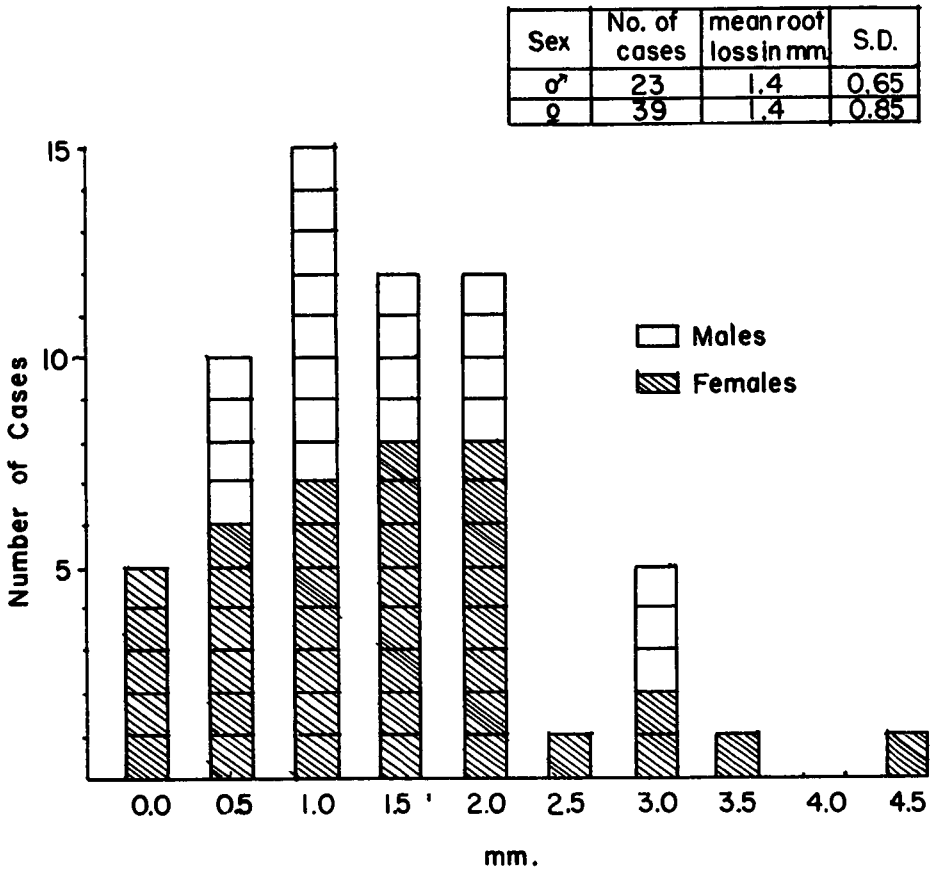

Table II. Frequency distribution of apical root loss in mm. of maxillary central incisors from lateral cephalometric films.

to indicate any significance of note must in these tests show a probability under 5 per cent.

II. *Measurement of apical root resorption from lateral cephalometric head films.*

1. *Sex differences and frequency distribution.* (Table II.) Loss of apical root structure varied from 0.0 to 4.5 mm. for the two groups. Females showed the greatest variance, having the least and greatest amounts of root loss. However, the mean root loss, 1.4 mm., was the same for each sex. In the male group, the standard deviation was 0.65 mm., in the female group, 0.85. In the entire series of 62, 30 cases (48.4 per cent) revealed one mm. or less of apical root loss; 54 cases (87 per cent) showed a loss of 2 mm. or less. A sharp break in distribution occurs at the 2 mm. loss level, with only 8 in the entire sample showing a loss of 2.5 mm. or above.

Since the mean for each sex group was found to be equal, there was considered to be no significant sex difference in apical root resorption. Frequency distribution was also unremarkable and further correlations were not

	No. of cases	*X root loss in mm.*	*S.D. in mm.*	*X age in years*	*S.D. in years*	*"r"*	*"t"*	*P*
Combined males and females	62	1.4	0.92	13.7	1.6	0.02	0.155	Over 50%

TABLE III.

Age of the patient at inception of treatment correlated with the amount of apical root loss. X symbolizes the mean.

pursued.

2. *Age of patient at inception of treatment.* (Table III.) For the entire group of 62 patients, the age range was from 10.75 to 18.5 years, with a mean of 13.7 years and a standard deviation of 1.6 years. Statistical evaluation of the data revealed a coefficient of correlation of 0.02. The "t" value (0.155) shows a probability well over any level of significance. No correlation was found between the amount of apical root loss and the age of the patient at the inception of treatment.

3. *Length of treatment.* (Table IV.) The amount of time that bands were cemented in place on the upper central incisors ranged from 5 to 24 months, with a mean of 12.5 months and a standard deviation of 4.2 months. Statistical evaluation revealed a coefficient of correlation of 0.13 with a "t" value of 0.101 well beyond any significance level. Therefore, this study indicates no correlation between the amount of apical root loss and the length of treatment period.

III. *Types of tooth movement.* (Tables V., VI., VII.) Evaluation of the findings in a series of 61 cases involving the three types of tooth movement previously defined are recorded here. In the original sample of 62, one case showed no movement during a treatment period of 16 months; therefore, it was not included

1. *Apical tipping.* Thirty-three cases fell into this classification. The degree of angular change, or amount of tooth movement during treatment, varied from 2.0 degrees to 28 degrees, with a mean of 15.5 degrees and a standard deviation of 7.8 degrees. The mean root loss was 1.6 mm. with a standard deviation of 1.28 mm. The coefficient of correlation revealed an "r" value of 0.038 indicating no relationship to the amount of apical root resorption and amount of tooth movement. The "t" value (0.212) indicated a probability of over 50 per cent to support this. The amount of apical root loss was not related in any way to the amount of tooth movement.

2. *Anterior or posterior apical displacement.* This group included 13 cases. The degree of angular change varied from 6.0 to 32.5 degrees with a

	No. of cases	*X root loss in mm.*	*S.D. in mm.*	*X treatment in months*	*S.D. in months*	*"r"*	*"t"*	*P*
Combined males and females	62	1.4	0.92	12.5	4.2	0.13	0.101	Over 50%

TABLE IV.

Length of treatment correlated with the amount of apical root loss.

Type of movement	*No. of cases*	$\overline{X}$ *angular change in degrees*	*S.D. degrees*	$\overline{X}$ *root loss in mm.*	*S.D. in mm.*	*"r"*	*"t"*	*P*
Apical tipping	33	15.5	7.8	1.6	1.28	0.038	0.212	Over 50%
Lingual bodily movement	15	5.25	3.9	1.33	0.97	0.053	0.190	Over 50%
Ant. or post. apical displacement	13	22.4	7.4	1.1	0.68	0.45	1.671	13%

TABLE V.

Types of tooth movement of maxillary central incisors: angular change correlated with the root loss for each type.

mean of 22.4 degrees and a standard deviation of 7.4 degrees. With the exception of one, a Class II, Division 2 malocclusion, all apices moved in an anterior direction. The mean root loss was 1.1 mm. with a standard deviation of 0.68. The highest correlation of root loss to the amount of tooth movement ("r" 0.45) occurred in this group. However, the "t" value (1.671) with a probability of approximately 13 per cent would place it outside any significant range. Therefore, the amount of apical root loss again is not related to the amount of tooth movement.

3. *Lingual bodily movement.* Fifteen cases were included in this classification. The angular change varied from 0.0 degrees to 12.5 degrees with a mean of 5.25 degrees and a standard deviation of 3.9 degrees. One case showed bodily movement plus some depression of the upper central. A second showed a little lingual movement but 3 mm. of depressing action. The mean root loss was 1.33 mm. with a standard deviation of 0.97. The value of "r" was 0.053 showing no correlation between apical root loss and the distance that tooth apices moved bodily and lingually. The "t" value (0.190) further bears this out showing a probability over 50 per cent, well over any significant range.

The Student "t" test again was used to evaluate any significant differences in the mean root loss of the different types of tooth movement. (Table VI.) A comparison of "apical tipping" to "lingual bodily movement" resulted in a "t" value of 0.452 with a probability above 50 per cent; "apical tipping" compared with "anterior or posterior

Apical tipping				Lingual bodily movement				*Anterior or posterior apical displacement*			
$\overline{X}$ Root loss	1.66 mm.	S.D.	1.28 mm.	$\overline{X}$ Root loss	1.33 mm.	S.D.	0.97 mm.	$\overline{X}$ Root loss	1.1 mm.	S.D.	0.68 mm.
				"t"		P		"t"		P	
				0.452		Over 50%		1.724		9%	

TABLE VI.

Test for possible significant difference between the types of tooth movement of the maxillary central incisors. Mean root loss of type "Apical Tipping" compared with mean root loss for "Lingual Bodily Movement" and Anterior or Posterior Apical Displayment".

Type of movement	No. of Cases	$\overline{X}$ movement apices ling. in mm.	S.D.	$\overline{X}$ root loss in mm.	S.D.	"r"	"t"	P
Lingual bodily movement	15	1.7	0.62	1.33	0.97	0.217	0.819	40%

TABLE VII.
Lingual bodily movement of apices in mm. correlated with the root loss.

apical displacement" showed a "t" value of 1.724 with a probability of approximately 9 per cent. Therefore, no significant difference can be noted between the mean root loss of the different types of movements.

IV. (Table VII.) In the 15 cases typed as "lingual bodily movement", the distance that the root apices moved lingually was correlated with the amount of apical root loss for that type. The movement of the apices lingually varied from one mm. to 3 mm. with a mean of 1.7 mm. and a standard deviation of 0.62 mm. The value for "r" (0.217) and the "t" value of 0.819 (probability 40 per cent) both show no correlation between the mean root loss and the distance the apices moved lingually. This result was noted with particular interest since this type of movement is the most difficult to perform with any orthodontic appliance and a greater amount of force is necessary to produce the lingual bodily movement of upper anteriors.

No correlation between the distance a tooth is moved during treatment could be shown with the amount of apical root resorption during treatment. It has been shown that all three types of movement occur under the edgewise appliance using a combination of round or square arch wires, but no significant difference could be drawn between the amount of apical root loss resulting from the three various types of movement.

V. *Surface area studies.* Results of mechanically simulated root loss indicated that, depending upon the size and shape of any central or lateral incisor, a 2 mm. loss of apical root structure leaves 5 to 10 per cent less area to the periodontal membrane for attachment. A loss of 4 mm. leaves 15 to 25 per cent less area for attachment, and a 6 mm. loss of apical root structure, 30 to 40 per cent less root surface for periodontal membrane attachment.

Table VIII. shows the effect that apical root resorption has upon the amount of root surface area left to the periodontal membrane for attachment to an apically resorbed tooth. These results are considered to be only approximate, since mechanical blunting can only approximate apical root resorption. Furthermore, only two each of maxillary and mandibular central and lateral incisors were used. This small sample could not take into account the infinite variety of lengths and shapes of the roots that exist. The area of each level of root loss was small

Tooth	2 mm.	4 mm.	6 mm.
$\underline{1\|1}$	8%	20%	38%
$\underline{2\|2}$	9%	23%	35%
$\overline{1\|1}$	7%	18%	32%
$\overline{2\|2}$	6%	18%	28%

TABLE VIII.
Tooth area lost for attachment to the periodontal membrane.

and the device used for measurement, a compensating polar planimeter, introduced a 5 to 10 per cent element of error into the measurements involved.

Discussion

The results of this investigation are at variance with conclusions drawn by a number of authors in the past and present strong implications that are contrary to accepted current beliefs in the profession. One of the main purposes for this study was to record systematically compiled data on the subject of apical root resorption for the purpose of evaluating these many divergent views.

In the intra-oral head film survey, the evaluation of the different degrees of resorption was done individually, and no attempt was made to influence the opinion of any investigator other than to set the standard classifications; "slight", "moderate", "excessive", or "questionable". Even so, the evaluations proved quite consistent. It was found that no one evaluator's classification stood out as consistently different from that of another. Differences of opinion did arise occasionally as to the degree of resorption, but the great majority of opinions converged.

As stated by other investigators (Ketcham,[4 5] Hemley,[20] Oppenheim[15]) the maxillary centrals and laterals were the teeth found to be most susceptible to apical root loss. Oppenheim[15] ascribed this to the fact that these were the teeth most affected by orthodontic treatment, for either cosmetic or functional reasons, and that the generally conical shape of the roots of these teeth transmitted appliance forces to the apex, thereby causing a tendency for apical root loss.

The incidence of susceptibility as reported in this study is much higher than that shown by other investigators, (Ketcham,[4 5] Hemley[20]) but comparison of results is difficult because different orthodontic appliances were used and other treatment concepts prevailed when the studies were reported. With the edgewise appliance, all teeth present in the mouth are banded with the possible exception of the maxillary and mandibular second molars which may not be erupted at the beginning of treatment and may or may not be banded when they do erupt. Under other appliances, fewer teeth may be banded as was the case in techniques of other years, which might partially account for a lesser incidence as reported. The methods of data presentation and interpretation are also different. Data presented by Ketcham showed a 21 per cent involvement of the number of teeth under orthodontic therapy. Rudolph[23 24] reported only percentages of patients involved with apical root loss (up to 100 per cent patient involvement if the period of treatment were long enough). Neither man reported the numbers of teeth involved nor the degree of apical root loss; i.e., "slight", "moderate", etc.

A study performed in a somewhat similar manner to the work herein reported was reported by Hemley[20] in 1941. The incidence of tooth involvement was reported as only 172 (3.5 per cent) of 4559 teeth subjected to orthodontic therapy. The incidence found in this study is much greater, but here again, close comparisons cannot be drawn because Hemley did not state the types of orthodontic appliances used nor the number of teeth banded and subjected to orthodontic forces. Uncompleted cases were included in his interpretation. Only 121 (62.1 per cent) of the 195 cases were completed, but the figure 195 was used in reporting patient involvement with root resorption (42 or 21.5 per cent of 195 cases.) This gives a lesser incidence than would

occur if the figure for completed cases (121) were used.

It is also noted that the number of uncompleted cases in his sample of 42 involved with apical root loss is not stated, but if some were used, it would influence in all probability the percentage of teeth in the different categories of resorption that Hemley set up, because it could not be determined whether or not a tooth had stopped resorbing when the evaluation was taken before completed treatment. Judging from the numbers of teeth studied, it would seem that no extraction cases were included in his sample. Therefore, no strict comparisons are possible between this and any studies available at present.

Teeth with injuries as evidenced by fracture lines or distortion of roots generally show a greater predilection to root resorption. (Figures 7-8.) A case designated in this study as "excessive" shows a distortion of roots of the right maxillary central and lateral incisors. It would appear that the roots of these teeth were distorted while forming, by a blow or injury of some kind, although the patient recalled no history of trauma to the area. This one case contributed 4 of the 5 teeth listed as an "excessive" degree of resorption. Loss of root structure was 4.5 mm. when measured on pre- and post-treatment lateral cephalometric head films. Other fractured anterior teeth were noted in the intra-oral films and were generally found to resorb more than their uninjured mates.

Incidence of root resorption of the maxillary and mandibular central incisors may be high but this study indicates that the actual amount of root loss is clinically insignificant except in the (5) extreme cases. The great majority of maxillary centrals were found to resorb 2 mm. or less with retentive area lost to the periodontal membrane

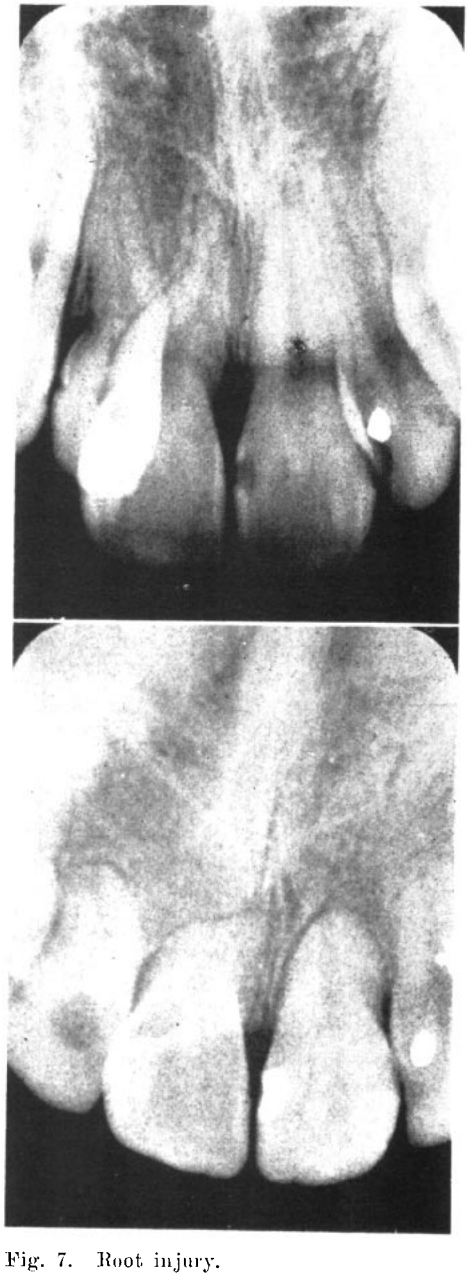

Fig. 7. Root injury.

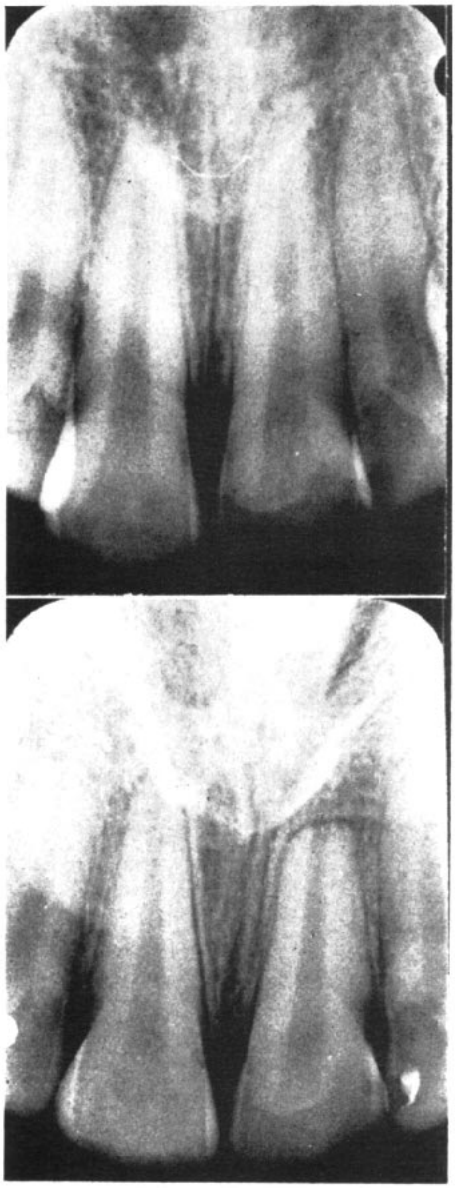

Fig. 8. Crown fracture

of less than 10 per cent. Only 7 cases in the cephalometric study fell into the category of losing 15 to 25 per cent of their retentive surface area. Only one case was found to have lost 30 to 40 per cent, and accounted for 80 per cent of the number of teeth classified as "excessive" in the entire intra-oral x-ray study. Actual root surface area lost to retention was shown to be minimal in an overwhelming majority of cases, and was remarkable in a very small number.

Summarily, the results of this study revealed no correlation between the amount of apical root loss and the age of the patient at inception of treatment, nor the length of the treatment period. This does not support the statements of Rudolph[24] that treatment is less hazardous to the root structure when initiated at an early age, and that the younger the patient the more prolonged the treatment can be without permanent loss of root structure. Neither the number of teeth involved nor any quantitative measure of apical root loss was presented to support the author's (Rudolph) views. Fischer[25] endorsed the theory that the younger the patient the less incidence and extent of root resorption and the shorter the treatment period the less extensive the root resorption. Both Fischer and Rudolph made a plea for treatment in mixed dentition, stating that the incidence and extent of apical root loss are less during the period when the root apices are not fully formed. Since the material considered here consisted entirely of full treatment cases with permanent dentitions, there are no concrete comparisons to be made. However, inspection of the intra-oral x-rays studied revealed that teeth without fully formed apices developed "normal" appearing shapes and contours to the apices even though under orthodontic treatment. The question still remains whether or not the roots under treatment develop to their full potential length, and in the light of the fact that there is no known method for concrete evaluation at present, it would seem reasonable to withhold support of the theory of Rudolph

Fig. 9. Distortion of root apices due to orthodontic intervention. Arrows indicate teeth and direction of movement.

and Fischer until a method is devised for further analysis.

Johnson, Appleton and Rittershofer[26] in 1926, reporting experiments on monkeys, noted an apical deformity of a young moved tooth. Boyle[27] cites the experiments on monkeys of Gottlieb and Orban in 1931, in which they reported that when orthodontic forces were applied to forming roots, there was deformation of Hertwig's sheath, and if the root end were allowed to fully form, there was a corresponding deformity in the root end. Oppenheim corroborated these animal experimentations with human material, showing a deformation of Hertwig's sheath and a consequent deformation of the calcified root tip. It would seem reasonable that deformity of the root tip would not allow the tooth to develop to its greatest potential length. As a consequence the root length is possibly shortened; on a fully formed root tip the "deformity" is affected as apical root resorption. Figure 9 shows an example of such a deflection of root apex due to orthodontic intervention. As can be seen, the teeth in question (mandibular first bicuspids) were involved in space closure following the removal of the mandibular second bicuspids in an extraction therapy case. The figure shows right and left sides of the same patient.

No significant difference was noted in this study between the amount of apical root loss resulting from the three various types of movement or between resorption and the distance a tooth was moved. This result was noted with particular interest in the "lingual bodily movement" category, a type involving the use of strong torque forces to overcome the difficult mechanical advantages due to the bracket position on the tooth. Hemley[20] supposed that bodily movement of apices of teeth through bone predisposed them to root resorption.

The selection and utilization of forces engendered by the various types of orthodontic appliances during treatment have been discussed in the literature for years by Schwarz,[13] Oppenheim,[15 16 17] Stuteville,[18 19] and others. That excessive forces during treatment can and do injure the teeth and supporting structures has been amply proven with every histologic investigation, both animal and experimental. All investigators are agreed on this point. Disagreement arises as to the amount of force that will cause tissue damage and how that force is applied. Schwarz[13] stated that the force which produced the most favorable type of tooth movement did not exceed the blood pressure of the capillaries (15-20 mm. of Hg.) which would be a force of 20-26 gms. per square cm. of tooth surface. This experimental evidence was based upon light spring pressures on the premolars of dogs. Stuteville[19] disagrees with Schwarz, stating that since "the premolar teeth of dogs do not occlude when the jaws are closed and since the dog's mandible does not have the same movement as that of humans, this material cannot be used to interpret human clinical material". He points out further that it is possible to move teeth without injury with a force of 100-200 gms. while on the other hand a 5 gm. force produced injury to the tooth and supporting structures. Stuteville[19] concludes: "root resorptions are produced in nearly all cases of orthodontically treated malocclusions and that injuries to teeth and supporting structures depend upon (1) amount and type of force, (2) distance through which the force is active, (3) forces other than those exerted by the appliance." (i.e., forces of mastication and occlusion).

Oppenheim[15] stated that physiologic movement of the teeth was impossible under orthodontic treatment but that to decrease the amount of permanent injury, the forces used to move the teeth should be light and intermittent with frequent periods of rest; and further that in order to obtain biologic reaction there does not exist a general admissible routine as to the amount of force or as to the extent of movement in a certain period of time, but that each treatment is an individual problem.

Oppenheim[15] also noted that clinical evidence of tissue damage is expressed in pain and loosening of the teeth, and that the absence of these is the sole criteria for judging that no severe damage has been done.

It appears that, at best, evidence to date can support only the fact that some injury to the teeth and supporting structures will result from orthodontic intervenion. Each individual must judge whether or not his orthodontic appliances are producing excessive injury and the criteria to be weighed are the benefits of treatment against possible injury to the teeth and supporting structures in each case.

Nonetheless, it is common knowledge that excessive root resorption has been known to occur without the presence of notable pain reaction during treatment. In view of the fact that periodontal membrane has been found to

average only 0.2 mm. in width,[16 19] the delicate appliance adjustments which direct a tooth movement that slight 0.2 mm. beyond which unwanted resorption of tooth root can occur to a varying degree, are exceedingly difficult to perform. Therefore, it would seem that some injury to root surface is unavoidable and that the lower levels of root loss as noted in the data are attributable to appliance forces.

Since the great majority of patients do not complain of pain with appliance adjustments that are necessary from time to time, the more extreme levels of apical root loss must be credited to an individual variation or, as has been suggested by some, to the resistance in a patient's metabolism to the tooth movement. This would indicate a possible endocrine or otherwise metabolic factor in excessive root resorption.

Metabolic or endocrine disturbances as a cause of loss of apical root structure have been considered by the orthodontic profession for years. In 1936, Becks[10] reported a study of 100 cases involving extensive apical root resorption, 50 cases with orthodontic intervention and 50 cases without. The results of the non-intervention cases show 40 (80 per cent) of the 50 cases to have a co-existent endocrinopathy. Of the treated cases, 46 (92 per cent) had a co-existing endocrinopathy. Of the cases with endocrinopathies, 40 of the treated cases and 33 of the untreated cases were diagnosed as hypothyroid. Becks' determination of hypothyroidism seemingly was based mainly upon an evaluation of the basal metabolic rate and blood cholesterol determinations. Other clinical tests for the diagnosis of hypothyroidism are noted in the paper but are not sufficienty documented by the data presented. In the light of present day medical knowledge, some serious doubt is cast upon the diagnoses of hypothyroidism as reported in his paper. Of the 16 cases reporting blood cholesterol levels and diagnosed as hypothyroid, the levels ranged from 163-238 mg. per cent, which lies within the present day accepted range of normal.[28 29] Today more accurate diagnostic tests such as radioactive iodine uptake, protein bound iodine, and cholesterol blood levels show that it is entirely possible to find a normal functioning thyroid gland and still have a basal metabolic rate of -20.[30] Of the basal metabolic rates reported in Beck's paper, only 10 of 40 orthodontically treated cases diagnosed as hypothyroidism had basal metabolic ratings below -20, and thirty-three untreated cases contained only 4 with a metabolic rating below -20.

Furthermore, the incidence of true hypothyroidism in childhood and adolescence is found to be very small. In fact, one of the largest clinics in the United States devoted to endocrine disturbances of children, reported only 100 cases of true hypothyroidism in adolescents in 13 years.[28] This does not coincide with the incidence Becks reported to the literature. For example, in one study 13 (9 per cent) of 145 prospective orthodontic patients were diagnosed as hypothyroid.[11] based upon routine physical examination. The orthodontic profession has accepted too often Becks' findings as true cause and effect relationship. Becks himself does make a statement, greatly obscured, however, by his previous reports: *"The mere frequency with which endocrinopathies are found in patients with root resorptions, however, does not permit as yet any conclusion that these conditions have produced the resorption."*[12]

The high incidence of "atrophic and dystrophic" bone conditions found to coexist with apical root resorptions by Becks[10 12] has not been verified in the literature by other researchers.

Marshall's work[6 7 8 9] presenting the

relationship of dietary factors to apical root loss has not been substantiated. It is entirely possible that there is some metabolic function (endocrine, dietary or other) producing the higher levels of apical root loss found to occur, and it is so suggested by the results of this paper.

Documentation in the literature of these suggested factors is inconclusive at the present time, however. More research is necessary to establish any sound basis for the suggested relationship between these factors and apical root loss.

The surface area studies presented show that the actual root surface area lost to retention of the periodontal membrane is small in the majority of cases.

Opinion differs among investigators with regard to two additional factors involved in the tooth retention apparatus; namely, the loss of root length, and the loss of alveolar process around the neck of the tooth during orthodontic treatment. Oppenheim[16] believes that shortened roots cannot resist the stress of function as well or as long as roots of normal length and that the situation is worsened with advancing age when the extra-alveolar lever becomes longer through normal aging processes. Hemley[29] agrees. On the other hand, Brodie[31] believes the process of apical root resorption has been greatly over estimated. He states that the retention apparatus is largely restricted to the coronal two-thirds of the root and that the apical one-third is relatively functionless in this regard. The loss of even a small amount of alveolar height (at the crest) is of greater significance. Shelton[31] and Tylman[31] bear out Brodie's statement, the latter stating that a tooth may be safely used as a bridge abutment so long as the length of the root exceeds that of the clinical crown.

No real clinical evidence has been presented in the literature to support these views. However, most authorities agree that due to the histologic factors involved, loss of alveolar processes about neck of the tooth is considered to be of greater harm to the retentive apparatus of the tooth; while loss of root surface area or apical root length is not considered to be of great clinical significance unless the loss is extreme.

Summary

1. The incidence of apical root loss in the great majority of cases as to number of teeth involved and degree of tooth involvement can be attributed to orthodontic appliance forces during treatment.

2. Except in extreme cases, numerically few, the degree of root loss is regarded as clinically insignificant and not endangering the life or function of the dentition.

3. No sex difference was discovered in the amount of apical root loss.

4. The age of the patient at inception of treatment was found not to have any correlation to the amount of apical root loss.

5. No correlation was noted between the amount of apical root loss and the length of treatment.

6. No correlation was demonstrated between the amount of apical root loss and the amount of movement of the tooth through bone.

7. Some metabolic factor (endocrine, dietary, or other) is suggested in the more extreme cases of apical root loss.

8. Documentation of metabolic factors (endocrine and dietary) in the literature, at the present time, is insufficient to regard these factors as definite etiologic causes of apical root resorption. More research is necessary to establish any positive correlation between etiologic factors and apical root loss.

9. An injured tooth, evidenced by crown fractures or root deformity, shows a greater predilection to root resorption than the uninjured tooth.

10. It is possible to cause a deflection of the Hertwig sheath of developing tooth roots due to orthodontic intervention. A loss of potential root length possibly may result from the deflection.

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